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GLACIAL WORK IN THE WESTERN MOUNTAINS IN 1901.[1]

DURING the season of 1901 some time was given to the study of Pleistocene problems in the western mountains. Four small parties, beside the writer, were in the field. The work of three of the four parties was the somewhat detailed study of selected areas, and was intended to make known the general conditions of glaciation at several somewhat widely separated localities. When a sufficient number of selected areas have been studied similarly, the results will afford a basis for preliminary conclusions concerning the course of Pleistocene history in the western mountains, and will be helpful in guiding future work. The work of this summer was intended as the beginning of study looking to this end.

The writer spent about six weeks in the region, mostly in association with the parties referred to. One party was in northwestern Montana, east of the Rockies; one farther west, on the western side of the Rockies, in northwestern Montana, northern Idaho, and eastern Washington; one in the Wasatch Mountains; and one in the mountains of New Mexico, a few miles northeast of Santa Fé.

The following brief summary will give some idea of the work done:

NORTHWESTERN MONTANA, EAST OF THE ROCKIES.

Mr. Fred H. H. Calhoun, accompanied by Mr. Bruce McLeish, spent three months in the northwestern part of Montana. The area studied, some 8000 square miles in extent, lies just south of the 49th parallel, and just east of the Rocky Mountains. It is the area in the angle between the Continental ice sheet from the northeast, on the one hand, and the Cordilleran ice sheet from the northwest, and the mountain glaciers from the west, on the other.

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[1] Published by permission of the Director of the U. S. Geological Survey.

The moraine formed by the northeastern ice sheet of the Wisconsin epoch was traced from Fort Benton, *via* Choteau, to the point where it crosses the 49th parallel, about longitude 112° 20′. From this point the moraine bends to the west and continues in this direction to the Watertown River, where it turns to the north, its course being nearly parallel to the mountains.

The moraines of fourteen glaciers from the Rocky Mountains were mapped. The recessional moraines of both the valley and continental ice masses were studied as far as time permitted. Study was also made of the extent of valley trains and outwash plains, and of the lakes which existed in front of the ice during the glacial period.

Among the results of the work, the following may be mentioned:

1. The westward and southwestward extension of the Wisconsin drift is greater than had been supposed.

2. The till of the northeastern ice sheet and that of the mountain glaciers overlap just south of the 49th parallel, between the meridians of 113° 10′ and 113° 15′. At no other point south of the boundary line did the ice from opposite directions occupy the same territory; but in Two Medicine Valley (latitude 48° 30′) the ice from the east advanced to within two miles of the position occupied at an earlier time by the ice from the mountains.

3. The ice sheet from the northeast reached its most advanced position after the valley glaciers from the west had retreated, for the drift of the former overlies the drift of the latter at various points, both north and south of the national boundary. In some cases the till from the northeast overlies the till from the west. This is true in the locality mentioned under 2, and farther north in the valleys of St. Mary's River, Belly River, and Lees Creek. In other places the till from the east overlies fluviatile deposits connected with the western drift, but extending down the valleys some miles beyond (east of) the ends of the mountain glaciers. In still other cases lacustrine

and berg deposits, having their source in the northeastern ice, overlie the till laid down at an earlier time by the mountain glaciers.

4. The valley glaciers belonged to a recent epoch. They were certainly not earlier than the Iowa epoch, and probably as recent as the Wisconsin.

5. The drift of the northeastern ice sheet is of Wisconsin, possibly late Wisconsin age.

6. So far as the evidence gathered shows, the length of time which elapsed after the deposition of the Rocky Mountain drift, and before the deposition of the drift of the ice sheet from the northeast, was not great.

7. The time since the last glacial epoch, as shown by several lines of evidence in the area studied, seems to have been geologically short.

8. The Sweet Grass Hills, situated just south of the 49th parallel and about thirty miles back from the edge of the ice sheet from the northeast, were not covered by the ice. The hills stood as three great nunataks, the highest reaching about 2000 feet above the surface of the ice.

9. The slope of the surface of the continental ice sheet between its edge and a point 25 miles back from its edge was estimated at about 50 feet per mile. This determination was made in the vicinity of the Sweet Grass Hills. The slope of the surface of the ice in various valleys was also determined.

10. The existence of a long narrow lake in front of the edge of the Continental ice sheet, and between it and the mountains, was proved, and its extent determined.

11. Considerable changes in drainage were effected by the ice. Some data were gathered which throw light on the former courses of the Missouri, the Teton, and the Two Medicine rivers, and of Buck, Muddy, and Cut Bank creeks.

Besides these conclusions touching glacial problems, some other observations were made:

12. The region studied shows at least three periods of erosion, when the land stood at different levels.

13. The high-level quartzite gravels on the plains east of the mountains are believed to be deposits made by streams at the close of the first epoch of base-leveling recorded in the present topography.

14. The strata at the mouth of Sun River and Muddy Creek canyons contain fossils of Carboniferous age. Rocks of the same age prevail in the whole of the eastern face of the mountains, where their thickness is several thousand feet.

Some other scattering data were collected touching the general geology of the region studied.

BETWEEN THE ROCKIES AND THE CASCADES IN NORTHWESTERN MONTANA, NORTHERN IDAHO, AND EASTERN WASHINGTON

Messrs. George H. Garrey and Eliot Blackwelder spent most of August and September in the study of glacial phenomena in northwestern Montana, northern Idaho, and northeastern Washington, most of the time being spent in the latter state, between Chelan Falls and Newport. The moraine of the ice lobe which came south through the Okanogan Valley, loops southeastward from Chelan Falls to a point about six miles west of Coulee City, where it bends northeastward to a point five miles north of the city, on the bluff of the Grand Coulee. Morainic material not aggregated into a marked terminal moraine, continues northward along the entire western rim of the Coulee. During glacial times the ice probably blocked the Columbia at its junction with the Grand Coulee, forcing the waters of the Columbia down the Coulee, as has been suggested by Russell and others. That glacial drainage followed the course indicated is suggested by the fact that the terraces of the Columbia above the Coulee are continuous with terraces in the Coulee.

Northeast of the junction of the Grand Coulee with the Columbia, the moraine of the Okanogan or Coulee City lobe takes the form of a well-developed ridge which, at a point about five miles north of the junction of the Columbia and the Grand Coulee, the most northerly point where it was seen, was trending slightly to the west of north. After continuing northward for a distance, this moraine probably loops eastward around the mountains in the Colville Indian Reservation, connecting with the moraine of the ice lobe which occupied the Columbia valley, north of its junction with the Spokane. The Okanogan or Coulee City ice lobe was about thirty-five miles wide in the latitude of Chelan Falls, and nearly fifty miles wide at the upper end of the Grand Coulee.

The moraine of the ice lobe which came down the valley of the Columbia, just west of the meridian of 118°, was traced southward from a point in the Colville Indian Reservation about three miles west of Kettle Falls on the Columbia, to the point where it crosses the Columbia seven miles southwest of Fruitland. Between these points, the moraine lies three to six miles west of the Columbia. Just east of the Columbia the moraine is lost in the terraces at the junction of the Columbia and Spokane valleys. From this point the moraine was traced northeastward, passing about three miles east of Fruitland, and thence along the west face of the mountains, to the Huckleberry Mountain in the S. E. corner of Tp. 32, R. 38, E. (about latitude 48° 15′). At this point it loops around and over the northeastern end of this mountain, and then turns southward in the Colville River Valley. The glacier of the Columbia Valley had a width of about six and one-half miles in latitude 48°, and a width of about fifteen miles, fifteen miles farther north.

As already mentioned, the moraine of the Columbia glacier loops over and crosses Huckleberry Mountain and becomes continuous, in the Colville Valley, with a lobe of ice which descended that valley to Springdale. The moraine of the east side of this lobe was traced northward along the mountains east of the Colville Valley, to Old Dominion Mountain, seven miles east of Colville. This seems to be the latitude where the moraine swings across the mountains to the east, though the crossing was not demonstrated. The Colville glacier had a width of about thirteen miles at Valley, about eight miles north of the southern end of the lobe. The width of the combined Colville and

Columbia glaciers just north of their union (lat. 48° 15′ approximately), was about thirty-three miles.

In the Pend d'Oreille Valley there was another ice lobe, which extended down the valley to a point three miles southwest of Davis Lake. To the northwest this moraine is believed to connect with that of the Colville lobe, north of Old Dominion Mountain, though this connection was not established. The moraine of this lobe crosses the Pend d'Oreille River to the eastward at the great bend of the stream eight or ten miles above Newport. East of the Pend d'Oreille the moraine of the east side of this ice lobe was judged, on the basis of topography, to turn northward.

Another ice lobe came down the Kootenai Valley, but its southernmost limit was not determined. On the basis of data gathered at other times by Professor Chamberlin and the writer, the ice of the Kootenai Valley is believed to have extended to the southern boundary of Pend d'Oreille Lake. It is possible that the Kootenai lobe connected to the northwestward with the Pend d'Oreille lobe; but, if so, the connection is well to the north of Bonners Ferry, and probably north of the boundary line.

It remains to be determined whether the Okanogan, Columbia, Colville, Pend d'Oreille, and Kootenai glaciers were marginal lobes of a single continuous ice sheet, the body of which lay to the north, or whether some of them had separate sources in the mountains. The connection of the second and third of these lobes was established, and data at hand make the connection of the third and fourth seem probable. The connection of the first with second, and of the fifth with fourth, if such connection exists, is probably near the boundary if not beyond it. In any case, the glaciers partially traced out were large—quite beyond the Alpine class.

A few data concerning glaciation farther east were also gathered. General glaciation did not occur as far south as Newport at the east line of Washington. Above Libby (in the Kootenai Valley near the west line of Montana) there was general glaciation from the north, though a few miles south of the river in this longitude drift from the north comes in contact with drift from the Cabinet Mountains. Whether the glaciation from opposite directions was contemporaneous, was not determined. Deposits of lacustrine clay some 300 feet thick in the valley near Libby, point to notable interruptions of drainage during glacial time, and probably to considerable changes since.

The Flathead valley contained a great glacier which advanced southward beyond the southern end of Flathead lake, though the southern limit of the ice was not traced out this season. In the latitude of Kalispell, the ice of this valley was about 3000 feet thick, as shown by the height to which the west face of the Kootenai Mountains east of the valley, was glaciated. The general direction of ice movement in this valley at Kalispell, and between this place and the lake, was south-southeast. The main body of the ice, therefore, came down the valley from the north northwest, and not from the mountains immediately east or northeast, though the main glacier was reënforced to some extent by ice from this direction. The source of ice which moved to the south-southeast was not determined. One lobe of the Flathead glacier moved southwest up the valley of Ashley Creek (the valley followed by the Great Northern Railway west of Kalispell), and another advanced westward a short distance beyond the end of the west arm of Flathead Lake.

The face of the Kootenai Mountains east of the Flathead Valley is abrupt, and not deeply indented. From the slight amount of study given to this face of the range, it would appear that local glaciation here was not of great extent or severity, for some of the considerable mountain ravines opening out to the west afford little evidence of glaciation. On the other hand, glaciation was severe in some of the valleys, as in that followed by the Great Northern Railway east of the Flathead Valley.

THE WASATCH MOUNTAINS.

Mr. Wallace W. Atwood spent about two months in the study of the glacial phenomena of the Wasatch Mountains. He was accompanied and assisted by William Peterson, M. J. Averett, H. B. Atwood, and Arthur Church.

The portion of the Wasatch Mountains studied lies between the parallels of 40° 15′ and 41°. The maximum width of the range in this latitude is about twenty miles. The total area examined for glacial phenomena was about 1000 square miles.

Within this area, the positions of fifty Pleistocene glaciers exceeding a mile in length were determined. Traces of several smaller glaciers and of more than a dozen névé fields were also found and mapped. Of the fifty larger glaciers, seven reached the shore line of Lake Bonneville, and the moraines of at least three of them are clearly seen to be partially buried by the fluviatile deposits near the shore, or possibly by the shore deposits of the lake itself.

The elevation of a catchment basin necessary to give rise to a glacier in this region, was between 8000 and 9000 feet, and, except where the basins were very favorably situated, the latter figure is more nearly correct.

The crest line of the Wasatch Mountains is near the eastern border of the range. The valleys of the west slope are therefore much longer than those of the east, and the glaciers of the two slopes were, in a general way, of corresponding lengths. The number of ice tongues on the west was also much greater than on the east. Of the fifty glaciers over one mile in length, forty-six were west of the crest, and but four east of it. Of the ten glaciers which reach or exceeded five miles in length, nine moved westward and but one eastward. The Little Cottonwood glacier on the west slope was twelve miles long, while the greatest length reached by any glacier on the east slope was five miles. East of the crest, one glacier descended to an altitude as low as 6000 feet, and two others descended to 7000 feet. On the west slope fourteen glaciers descended to an altitude of less than 6000 feet, and seven to 5000 feet.

The greater number and size of glaciers on the west side of the range as compared with the east side, were determined by (1) the larger catchment basins, and (2) the heavier snowfall. A third factor, of local importance, was the accumulation of snow in catchment basins among the lofty peaks of two east-west divides, lying west of the main crest. These basins, in many instances, furnished tributary glaciers to the main canyons, and thus greatly increased the amount and strength of the work done by the ice on the west side of the range.

Glaciation was not only more extensive, but also more vigorous on the west side of the range than on the east. This is shown by a more complete cleaning out of loose material from the glaciated valleys of the west slope, by the more complete reduction of their asperities of surface, by the greater deepening of the main canyons on this side, leaving their tributary valleys "hanging" 200 to 300 feet above, and by the development of more massive moraines. The moraines of the east-slope glaciers are insignificant in comparison with those of the west slope glaciers.

The work of the season removes all doubt as to the duality of the ice age in the Wasatch Mountains. There were at least two ice epochs separated by a long interglacial interval. Evidence of more than two epochs was not found. The basis for the above conclusion is as follows:

1. In several valleys there are outer moraines, much older than the inner moraines of the same valleys. A considerable tunnel exposure in one of these outer moraines showed essentially all of the abundant granite bowlders, up to four feet in diameter, so thoroughly disintegrated that they had been cut through with picks and shovels in the excavation of the tunnel. Most of them could be crumbled by the hand. This condition of things was not superficial, but held to the depth of twenty feet, the deepest point of exposure.

2. In certain glaciated canyons there are such variations in the amounts of postglacial change (weathering, erosion, etc.) which different portions of the drift and valley walls have suffered, that it seemed necessary to postulate much longer exposure for certain parts than for others. In all such cases, the drift which appears to be older, extends beyond that which

appears to be younger. The ice of the earlier epoch, therefore, seems to have been more extensive.

3. Two distinct sheets of drift were found at several points in the valleys of both the North and South Forks of the American Fork. These sheets of drift are separated by a soil twelve to eighteen inches thick. In the same localities, the soil on the surface of the upper drift sheet, formed since the last retreat of the ice, is from four to six inches thick. So far as the thickness of soil is a basis for estimating time, it would indicate that the interval between the ice epochs was longer than the time since the last.

The topography of the region examined was somewhat modified by glaciation. The valleys which were occupied by ice are usually U-shaped, and their slopes are commonly smoothed off as far up the sides as the ice reached. Such forms are in sharp contrast with the V-shaped canyons and rugged slopes of the valleys not occupied by ice. In some of the glaciated valleys massive moraines were built up. These are sometimes in the canyons, and sometimes at their débouchures, according to the position which the ends of the glaciers reached at the time of their maximum extension. When tributary glaciers joined the main, medial moraines were formed, and as the ice melted, these moraines were left as ridges, parallel with the course of the valley. Recessional moraines are frequently found crossing the valleys as crescentic ridges, convex down stream. These ridges often served as dams, above which lakes accumulated, rose, and overflowed. The outlet streams of such lakes cut gorges in the moraines. Near the heads of many valleys the ice gouged out rock basins, 50 to 200 feet in diameter and from 5 to 20 feet in depth. At least thirteen of the thirty-six glacial lakes mapped, are in rock basins apparently made by the ice.

The relation of the moraines at the west base of the Wasatch, to the fluviatile (or shore) deposits in the Bonneville basin, is such as to indicate, as Gilbert has pointed out, that the last advance of the ice from the mountains occurred during a late period in the history of Lake Bonneville. The close correlation of the earlier ice epoch with the earlier wide extension of the Bonneville waters cannot as yet be asserted, although the data at hand strongly suggest the contemporaneity of the early expanded stage of Lake Bonneville and the early glaciation.

THE MOUNTAINS NEAR SANTA FÉ

Messrs. John E. Webb and William A. Averill spent about one month in the mountains of New Mexico, a few miles northeast of Santa Fé. The area studied was the Santa Fé range of the Rockies, which traverses the northeastern portion of New Mexico, running in a general north-northeast, south-southwest direction through the adjacent parts of Santa Fé, Rio Arraba, Mora, and San Miguel counties, between the parallels of 35° 45′ and 36°, and the meridians of 105° 35′ and 105° 50′. The aggregate area comprises about 250 square miles.

The height of the range in the area studied varies from 7000 feet to 13,306, feet, the latter being the altitude of the highest of the Truchas peaks. The altitude which seems to have been necessary for the generation of glaciers was 11,700 to 12,000 feet. The following peaks attained the requisite height: Lake peak, 12,380 feet; Baldy peak, 12,623 feet; Pecos Baldy (Cone peak?), 12,550 feet; Jicarilla peak, 12,944 feet; and the Truchas group, the highest peak of which is 13,306 feet. Clear evidence of glaciation was not seen on lower peaks, though it cannot be said that many of the lower peaks were studied in the detail necessary to demonstrate the complete absence of glaciation.

Heading against these peaks and their connecting ridges, fifty cirques bearing evidences of glaciation were observed. Névé fields, with incipient motion, existed at some points where well-formed glaciers did not develop. Sixteen of the cirques are in the group of mountains (Lake, Baldy, and associated ridges) at the head of Santa Fé Creek; seven in the Pecos Baldy group; twelve among the Truchas peaks; and fifteen about Jicarilla peak, and the ridge between it and the Truchas peaks. Of these cirques, twenty-five open toward the east, thirteen toward the north, seven toward the south, and five toward the west. The cirques range from one-fourth of a mile to two miles in width, and from one-eighth of a mile to two and one-half miles in length, and from 150 to 1000 feet in depth. Most of them contain lakes or ponds, some of them as many as six, and almost all contain flats or bogs, indicating the former existence of standing water, where there is none now. The total number of ponds and lakelets seen was about eighty. Since they were seen in the rainy season, the number of permanent bodies of standing water may be less.

The longest glacier track studied is in the valley of the Santa Fé Creek. The ice emanating from three cirques united to form a single glacier which Messrs. Webb and Averill think extended some seven miles down the valley, its lower end reaching down to an altitude of about 9200 feet, the lowest altitude, so far as seen, to which the ice descended. The largest area of glaciation from a single source is that on the east side of the Pecos Baldy group, in the valley of Jack's Creek, while the largest continuous area of glaciation (to which the ice from several sources contributed) is that along the group of mountains at the head of Santa Fé Creek.

The moraine matter left in the cirques, and in the valleys below them, often has a pronounced hummock-and-hollow topography. Its composition varies from point to point. The chief accumulations are in the bottoms of the valleys. The morainic matter is often disposed in ridges most commonly roughly parallel to the axes of the valleys and to the direction of ice movement, but often oblique or even at right angles to this direction.

Striæ were found on *roches moutonneés* in several places, while smoothed and polished rock surfaces are of frequent occurrence.

The higher ridges and peaks of the glaciated regions are serrate, but serrate crests are confined strictly to the higher parts of the range. Serration often characterizes the tops of the mountains, on the sides of which the glaciated cirques lie.

OTHER OBSERVATIONS

In addition to the foregoing work, some further data were gathered at several points, touching Pleistocene geology in the West. It was found that loess has somewhat extensive development in eastern Washington and northeastern Oregon, though its limits were not determined. It is widespread in Douglas, Lincoln, Whitman, Columbia, Walla Walla and probably Spokane counties, Washington. It is very generally distributed over the northern part of Umatilla county, Oregon. In geographic distribution it seems to correspond, in a general way, with the great wheat belt of the states mentioned. In topographic distribution, it has the general habit of the corresponding formation in the Mississippi basin; that is, it has a preference for considerable elevations. So far as seen, however, its disposition to follow streams is less pronounced than in the Mississippi basin east of the Missouri. Its variations in composition and structure, too, are similar to those of the loess of the interior. Its thickness is very variable, and for the most part undetermined, but locally it is at least twenty-five to thirty feet thick, and its maximum is probably considerably more. In many places, as at Bolles Junction (Walla Walla county), it abounds in calcareous concretions of the usual loess type. In other places, as at Alto (Columbia county), it assumes the columnar structure, so characteristic of the loess of some other localities where the formation is well known. In many places, it constitutes the entire mantle rock. In some places it is associated with sand, which may be either beneath it or interbedded with it; and in other localities it contains considerable beds of volcanic ash. The sand and volcanic ash associated with it are sometimes distinctly stratified. In some cases, the stratification is clearly the work of wind, but in others this was not evident. The impression gained was that much of the loess seen is of eolian origin.

Observations on glaciation were made at several points, aside from those enumerated in the preceding pages. Data sufficient for the intelligent direction of future Pleistocene work were gathered for a number of localities where detailed work in the near future seems desirable. In addition to preliminary studies of this sort, glaciation was found to have occurred in some localities from which it has not heretofore been reported. For example, it was found that glaciers affected the north slope of both the Spanish Peaks of Colorado. These mountains, 12,708 and 13,623 feet high respectively, appear to have represented about the limiting conditions for glaciation, for the glaciers of both mountains were small, and confined to their northern slopes. One of the limiting conditions here was doubtless the small area which could serve as a catchment basin on either peak. Had the areas of these mountains been larger, more considerable glaciation would doubtless have been developed at this altitude.

It was found, among other things, that the detailed study of glacial problems will locally have an important economic bearing. An extensive placer mining plant is being established at Breckenridge, Col., to wash the glacial moraine matter of the Blue River valley, and the gravels of the valley train below.

ROLLIN D. SALISBURY.